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The technical topic of the project was the experimental observation of Coulomb crystallization of charged microspheres levitated in a gas discharge plasma. This suspension, sometimes termed a dusty plasma, is closely analogous to a colloidal suspension, except that it has a much faster time response, is more optically thin, and has no buoyancy forces to suspend the particles. The particles are levitated by electric fields. Through their collective Coulomb repulsions, the particles arrange themselves in a lattice with a crystalline symmetry, which undergoes an order-disorder phase transition analogous to melting when the effective temperature of the system is increased. Due to gravitational sedimentation, the particles form a thin layer in the laboratory, so that the experimental system is nearly 2D, whereas in future microgravity experiments they are expected to fill a larger volume and behave like a 3D solid or liquid. The particles are imaged using a video camera by illuminating them with a sheet of laser light. Because the suspension is optically thin, this imaging method will work as well in a 3D microgravity experiment as it does in a 2D laboratory system.

During the course of the three year project, we developed this new type of instrumentation and the data analysis methods. This led to a number of publications in refereed journals, as listed below. Among the significant discoveries we made were these:

- The 2D crystal melts, and between the crystalline and liquid phases it exhibits the properties of the "hexatic intermediate melting phase" predicted by the theory of Kosterlitz and Thouless. The Kosterlitz-Thouless model fails to predict the two-phase melting observed in the experiments, however. In the experiments defects organize in large liquid like grain boundaries that separate otherwise crystalline grains.
- A new method of producing a direct 3D image of all the particles in a sample volume was developed. This allows microscopic diagnostics of structure that are not possible in 3D colloidal suspensions. The method involves constructing a 3D image from a stack of 2D images, each formed by video images of particles illuminated by a movable slice of laser light.
- Both body-centered cubic (bcc) and simple hexagonal structures are stable in our suspensions, and they can coexist even in the same suspension.
- The stability of the simple hexagonal structure is due to the anisotropic flow of ions in our experimental system. This was verified in simulation and experiment. The simulations were carried out in collaboration with Prof. Frank Melandso, of the University of Tromso in Norway, who spent a year at the University of Iowa working on this project.
- A compressional wave propagates through the ordered structure of particles when it is perturbed at its edge with a sinusoidal displacement. This wave obeys the dispersion relation predicted by the theory of dust-acoustic waves in a plasma, rather than that of a sound wave in a solid. In the field of strongly-coupled plasmas, we believe this paper represents the first experimental report of measurements of a wave dispersion relation.

In addition to these laboratory definition experiments, the NASA grant supported the costs of the PI's participation in the design of a DARA-funded get-away-special microgravity experiment, which is expected to fly in 1999.

Papers published under the support of NAG8-292

1. Chunshi Cui and J. Goree
Fluctuations of the Charge on a Dust Grain in a Plasma
IEEE Transactions on Plasma Science, Vol. 22, pp. 151-158, 1994
2. H. Thomas, G. Morfill, V. Demmel, J. Goree, B. Feuerbacher, and D. Mš hlmann
Plasma Crystal: Coulomb Crystallization in a Dusty Plasma
Physical Review Letters Vol. 72, pp. 652-656, 1994
3. J. Goree
Charging of Particulates in a Plasma
Plasma Sources Science and Technology Vol. 3, pp. 400-406, 1994
4. G. Praburam and J. Goree
Observations of Particle Layers Levitated in an rf Sputtering Plasma
Journal of Vacuum Science and Technology A Vol. 12, pp. 3137-3145, 1994
5. F. Melandsi and J. Goree
Polarized Supersonic Plasma Flow Simulation for Charged Bodies such as Dust Particles and Spacecraft
Physical Review E Vol. 52, pp. 5312-5326, 1995
6. J. Goree
Charge on Dust Grains with a Finite Number Density in a Plasma
IEEE Transactions on Plasma Science [accepted 1995]
7. R. A. Quinn, C.S. Cui, J. Goree, J. B. Pieper, H. Thomas and G. Morfill
Structural Analysis of a Coulomb Lattice in a Dusty Plasma
Physical Review E Vol. 53, pp. 53-56, 1996
8. J. Pieper, J. Goree and R. A. Quinn
Experimental Studies of 2D and 3D Structure in a Crystallized Dusty Plasma
Journal of Vacuum Science and Technology A Vol. 14, pp. 511- 518 1996
9. F. Melandsi and J. Goree
Particle Simulation of Two-Dimensional Dust Crystal Formation
Journal of Vacuum Science and Technology A Vol. 14, pp. 519- 524 1996
10. J. B. Pieper, J. Goree and R. A. Quinn
Three-dimensional structure in a Crystallized Dusty Plasma
Physical Review E Vol. 54, pp. 5636-5640 1996
11. J. B. Pieper and J. Goree
Dispersion of Plasma Dust-Acoustic Waves in the Strongly-Coupled Regime
Physical Review Letters Vol. 77, pp. 3137-3140 1996

Education

<i>California Institute of Technology</i>	B.S.	Applied Physics	1980
<i>Princeton University</i>	M.A.	Plasma Physics	1982
<i>Princeton University</i>	Ph.D.	Plasma Physics	1985

Professional Experience

<i>The University of Iowa</i>			
<i>Dept. of Physics and Astronomy</i>	Assistant Professor		1985 - 1991
Associate Professor			1991 - 1996
Professor			1996 – present
<i>Max-Planck Institut für extraterrestrische Physik</i>			
<i>Garching, Germany</i>	Guest Scientist		1991 – 1992
Guest Scientist			1998

Consulting Experience

<i>Norand Corp.</i>	Plasma processing		1985 - 1988
<i>Eastman Kodak Co.</i>	Computer simulation of magnetron erosion		1989 - 1990
<i>Applied Materials</i>	Computer simulation of magnetron erosion		1995 - 1996
<i>Catalina Coatings</i>	Computer simulation of magnetron erosion		1997

Awards

<i>IBM</i>	Faculty Development Award		1986
<i>Univ. of Iowa</i>	Faculty Scholar Award		1995

Research Interests

Plasma physics experiments and modeling:
 Dusty plasmas
 Strongly-coupled plasmas
 Plasma processing discharges
 Laser diagnostics of plasmas

Professional Society Membership

American Physical Society
American Vacuum Society
Institute for Electrical and Electronic Engineers